AD-A125 292 VALIDATION OF BRAIN EVENT-RELATED POTENTIALS AS INDICATORS OF COGNITIVE S..(U) NAVY PERSONNEL RESEARCH AND DEVELOPMENT CENTER SAN DIEGO CA P FEDERICO ET AL. 1/1

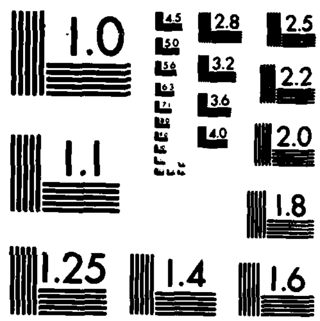
UNCLASSIFIED FEB 83 NPRDC-TR-83-11 F/G 5/10 NL

END

DATE FILMED

83

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NPRDC TR 83-11

February 1983

VALIDATION OF BRAIN EVENT-RELATED POTENTIALS AS INDICATORS OF COGNITIVE STYLES, ABILITIES, AND APTITUDES

Pat-Anthony Federico
Jeffrey N. Froning
Marlene Calder

Reviewed by
John D. Ford, Jr.

Released by
James F. Kelly, Jr.
Commanding Officer

Navy Personnel Research and Development Center
San Diego, California 92152

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NPRDC TR 83-11	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) VALIDATION OF BRAIN EVENT-RELATED POTENTIALS AS INDICATORS OF COGNITIVE STYLES, ABILITIES, AND APTITUDES		5. TYPE OF REPORT & PERIOD COVERED Interim Report Oct 1979-Oct 1980
		6. PERFORMING ORG. REPORT NUMBER 13-80-10
7. AUTHOR(s) P-A. Federico M. Calder J. N. Froning		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Navy Personnel Research and Development Center San Diego, California 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62763N ZF63-522-010-03.06
11. CONTROLLING OFFICE NAME AND ADDRESS Navy Personnel Research and Development Center San Diego, California 92152		12. REPORT DATE February 1983
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Evoked cortical potentials
Event-related potentials (ERPs)
Cognitive styles, abilities, and aptitudes
Hemispheric function
Cognitive processing
Human information processing
Brain activity
Lateral asymmetry
Individual differences
Construct validity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Fifty Navy recruits were given 11 paper-and-pencil tests of cognitive styles, abilities, and aptitudes. Visual, auditory, and bimodal brain event-related potential (ERP) amplitudes were recorded from each of these subjects. Product-moment and canonical correlational analyses, as well as principal-factor analysis and varimax rotation, were conducted. Product-moment correlations indicated that some cognitive attributes were significantly associated with some ERPs. Cognitive characteristics that contributed to the significant canonical correlations were general aptitude, verbal comprehension,

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

spatial ability, field dependence-independence, conceptualizing style, and reflection-impulsivity, as well as ERPs in the right temporal and parietal areas and left frontal and parietal areas. Some ERPs and cognitive characteristics defined the same underlying dimensions, implying that they are related. The results demonstrated the construct validity of ERPs as indicators of individual differences in cognitive characteristics, especially crystallized and fluid intelligence.

FOREWORD

This research was performed under exploratory development work unit ZF63-522-010-03.06, Evaluating Evoked Potentials for Navy Training and Testing, under the sponsorship of the Chief of Naval Material (Office of Naval Technology). The goal of this work unit is to assess the feasibility of using brain event-related potentials (ERPs) in Navy training and testing.

A previous report prepared under this work unit (NPRDC Tech. Rep. 82-8) discussed the use of ERP analysis to aid in the design of instructional procedures adapted to the information-processing strategies of individual students. It suggested the possibility of increasing Navy training efficiency by taking better advantage of the variabilities that exist among students in their sensory modalities. The purpose of this study was to ascertain the construct validity of brain ERPs as indicators of individual differences in cognitive processing.

Other NAVPERSRANDCEN publications that are related to this effort described student cognitive characteristics and academic achievement (NPRDC Tech. Reps. 79-1, 79-21, 79-30, and 80-23) and the relationship between ERP measures and performance (NPRDC Tech. Note 7-7 and Tech. Reps. 77-13, 79-13, and 80-26).

Special appreciation is extended to Dr. Gregory W. Lewis, NAVPERSRANDCEN, for his assistance during the data collection phase of this research.

The results of this study are primarily intended for the Department of Defense training and testing research and development community.

JAMES F. KELLY, JR.
Commanding Officer

JAMES W. TWEEDDALE
Technical Director

[illegible]

Objective

The purpose of this research was to determine the construct validity of ERPs as indicators of individual differences in human cognitive characteristics, as those differences are assessed by traditional paper-and-pencil psychometric tests.

Approach

Paper-and-pencil tests of cognitive styles, aptitudes, and abilities were administered to 30 Navy recruits. Visual, auditory, and bimodal ERPs were recorded from each subject. Using the test scores and ERP measures as input, product-moment and canonical correlational analyses, as well as principal-factor analysis with varimax rotation, were conducted.

Results

The results of the product-moment correlational analyses indicated that field dependence-independence, reflection-impulsivity, tolerance of ambiguity, cognitive complexity, general aptitude, reading skill, verbal comprehension, spatial ability, and logical reasoning were significantly associated with visual, auditory, and/or bimodal ERPs or brain asymmetry measures as well as sensory interaction indices. The significant correlations ranged from -.47 to .43 with many hovering in the .3's. Higher correlations (in the .4's) involved spatial ability with ERPs elicited visually in the left parietal and occipital areas as well as with derived indices of sensory interaction in the left frontal region. The significant canonical analyses revealed that some cognitive attributes and brain ERPs have from 45 to 65 percent variance in common. The cognitive characteristics that contributed to the canonical correlations were conceptualizing style, reflection-impulsivity, general aptitude, verbal comprehension, field dependence-independence, and spatial ability, as well as ERPs in the right temporal and parietal areas and left frontal and parietal areas. The varimax factor rotation demonstrated that some ERPs and cognitive attributes defined the same underlying independent dimensions. That is, they weighted the same factors, implying that they are related (e.g., visual and bimodal asymmetry in the frontal brain sites and reading comprehension).

Conclusions

1. There are significant relationships between some ERPs and cognitive characteristics (e.g., field independence was negatively correlated with auditorily evoked ERPs in the left occipital area).

2. [illegible]

3. ERPs appear to indicate individual differences in [illegible] processes [illegible] and in fluid intelligence, [illegible]

4. The results demonstrate the construct validity of brain ERPs as indicators of human cognitive processing.

Direction of Research

Since ERPs appear to be valid measures of individual differences in human information processing, especially in crystallized and fluid intelligence, they may provide a basis for adapting instructional techniques to Navy trainees and for developing improved methods of matching personnel to Navy jobs. Research is now underway that records ERPs prior to and during the initial learning and subsequent performance of Navy-relevant, real-world, information-processing tasks (e.g., tasks involving the detection, analysis, recognition, and classification of radar signals). Learning and performance indices are being related to the ERP measures to determine further their usefulness for designing adaptive instructional strategies and predicting student performance.

CONTENTS

	Page
INTRODUCTION	1
Problem	1
Objective	1
Background	1
Construct Validity	2
APPROACH	3
Subjects	3
Cognitive Characteristics Measured	3
Instrumentation	3
Stimuli	3
Procedure	5
Recording Sites	5
Electrodes	5
ERP Data	6
Statistical Analyses	8
RESULTS	8
Product-moment Correlational Analyses	8
Canonical Correlational Analyses	18
Factor Analysis	18
Rotated-factor Solution	20
DISCUSSION AND CONCLUSIONS	22
DIRECTION OF RESEARCH	26
REFERENCES	27
DISTRIBUTION LIST	33

LIST OF TABLES

Page

1. Cognitive Characteristics Measured in this Research 4
2. Descriptive Data for Cognitive Characteristics 9
3. Descriptive Data for ERPs and ERP Asymmetries 9
4. Descriptive Data for Sensory Interactions 10
5. Correlations Between ERPs and Measures of Cognitive Style 11
6. Correlations Between ERPs and Measures of Aptitude and Ability 12
7. Correlations Between ERP Asymmetries and Measures of Cognitive Style 13
8. Correlations Between ERP Asymmetries and Measures of Aptitude and Ability 14
9. Correlations Between Sensory Interactions and Measures of Cognitive Style 15
10. Correlations Between Sensory Interactions and Measures of Aptitude and Ability 16
11. Summary of Significant Canonical Analysis Between Cognitive Characteristics and Event-related Potentials 19
12. Varimax-factor Matrix for the Brain Asymmetry Measures and Cognitive Characteristics Data 21

INTRODUCTION

Problem

Manpower shortages have made it necessary for the Navy to look for alternative techniques for increasing the effectiveness of its training programs. One way of doing this would be to develop procedures for adapting training to a wider range of student abilities, aptitudes, and cognitive styles. Recent advances in the computerized assessment of brain activity, especially in the measurement of brain event-related potentials (ERPs), suggest that this technology may be useful for estimating the cognitive characteristics of Navy trainees. If so, then it may be possible to design instructional procedures that accommodate the differences among individual students. However, before brainwave measures are employed in this manner, it must be established whether ERPs are valid indicators of individual differences in not only abilities and aptitudes but also cognitive styles.

Objective

The purpose of this research was to determine the construct validity of brain ERPs as indicators of individual differences in cognitive characteristics, as those differences are assessed by traditional paper-and-pencil psychometric tests.

Background

The average ability level of Navy recruits has noticeably decreased and then increased since the all-volunteer force was implemented. Consequently, the Navy is seeking innovative training strategies that can be used to adapt instruction to a wider range of student abilities, aptitudes, and cognitive styles. In an effort to accommodate training to the individual differences between students, the Navy implemented computer-managed instruction (CMI). CMI is partially adaptive, since the students use self-study materials and learn at their own pace. A second strategy, the aptitude-treatment-interaction (ATI) approach, assumes that aptitudes, as measured by customary psychometric tests, interact with instructional strategies or treatments. Research has only partially supported the ATI notion (Cronbach & Snow, 1977; Federico, 1978, 1981). Improved techniques for accommodating instructional techniques to the cognitive attributes of individual students are still needed, however (Federico & Landis, 1979a, 1979b, 1980).

Another possible approach would be to asses individual differences in information processing styles, as indexed by ERPs, and then develop training strategies that exploit these differences. At least two different modes of information processing have been shown to be related to the brain's two hemispheres. A verbal, analytic, sequential, logical mode of information processing has been associated with left-hemisphere activity in most right-handed individuals. Conversely, a spatial, integrative, simultaneous, intuitive mode has been attributed to right-hemisphere activity. These two modes of processing were initially discovered by anatomical studies using subjects with war wounds, lesions, and "split-brains."

Computer technology and measures of brain electrical activity have been applied to the study of these processes. Electroencephalographic (EEG) and ERP records depict brain activity as minute signals recorded from the scalp. The EEG shows on-going activity while the ERP shows activity after stimulus events (e.g., light flashes or audible clicks). Typically, for people performing verbal tasks such as reading prose passages, there is decreased activity over the left hemisphere. For spatial tasks such as recognizing random shapes, there is generally a decrease in activity over the right hemisphere. Such

decreases may be considered indices of increased information processing within the affected hemisphere.

Some individuals employ a predominantly verbal-analytic cognitive style for learning, problem solving, and decision making, whereas others employ a predominantly spatial-integrative cognitive style (Bogen, 1969; Callaway, 1975; Dimond & Beaumont, 1974; Galin & Ellis, 1975; Galin & Ornstein, 1972; Kinsbourne, 1978; Knights & Bakker, 1976; Lewis, 1979, 1980; Lewis & Rimland, 1979, 1980; Ornstein, 1977).

Many studies have investigated relationships between brain ERPs and indices of intelligence. ERP latencies seem to vary inversely with measures of ability or intelligence (Bigum, Dustman, & Beck, 1970; Callaway, 1973, 1975; Chalke & Ertl, 1965; Ertl, 1969; Ertl & Schafer, 1969; Galbraith, Gliddon, & Busk, 1970; Gucker, 1973; Marcus, 1970; Shucard & Callaway, 1974; Shucard & Horn, 1972). Yet, some investigations failed to establish such a relationship (Barnet & Lodge, 1967; Engel & Fay, 1972; Henderson & Engel, 1974; Osborne, 1970; Rhodes, Dustman, & Beck, 1969).

Right hemisphere ERP amplitudes and asymmetry measures appear to be directly related to intelligence--although not always (Bigum, Dustman, & Beck, 1970; Galbraith, Gliddon, & Busk, 1970; Perry, McCoy, Cunningham, Falgout, & Street, 1976; Rhodes, Dustman, & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini, & Morganstern, 1971; Shucard & Horn, 1973). Other ERP properties that have been explored with respect to intelligence have been habituation (Barnet, 1971), variability (Bigum, Dustman, & Beck, 1970; Callaway & Stone, 1969; Rhodes, Dustman, & Beck, 1969), and harmonic components (Bennett, 1968; Ertl, 1971, 1973; Shucard & Callaway, 1974, Weinberg, 1969).

A number of experiments have been conducted to explore associations between different aspects of human information processing and brain electrical activity (e.g., Buchsbaum & Silverman, 1970; Donchin, 1973; Donchin & Cohen, 1967; Donchin, Kubovy & Kutas, 1973; Friedman, Guyer-Christie, & Tumchuk, 1976; Horst, Johnson, & Donchin, 1980; Israel, Chesney, & Wickens, 1980; Israel, Wickens, Chesney, & Donchin, 1980; Pizzamiglio, 1976; Ray, Morell, Frediani, & Tucker, 1976; Shearer & Tucker, 1981; Squires, Petuchowski, Wickens, & Donchin, 1977; Tucker, 1981; Tucker & Shearer, 1977; Wickens, Mountford, & Schreiner, 1981). Very few of these investigations reported relationships between different ERPs and distinct cognitive styles as assessed by customary psychometric measures. Do ERPs have construct validity with respect to not only abilities and aptitudes but also cognitive styles?

Construct Validity

The American Psychological Association's Standards for Educational Tests and Manuals (1966, p. 13) states:

> Construct validity is evaluated by investigating what qualities a test measures; that is, by determining the degree to which certain explanatory concepts or constructs account for performance on the test. Essentially, studies of construct validity check on the theory underlying the test.

Investigations of construct validity are usually conducted to ascertain "what the test measures" in order to understand more fully the psychological characteristics or attributes contributing to test performance. When a test is proposed as a measure of a trait, its construct validity is established by determining its relationships to other tests

that purport to measure the trait. These relationships are often found by correlational or factor analytical methods.

APPROACH[1]

Generally, the approach consisted of correlating and factor analyzing ERPs with selected measures of individual differences in human information processing (i.e., cognitive styles, abilities, and aptitudes).

1. Cognitive styles (e.g., tolerance of ambiguity) are the dominant modes of information processing that people typically employ when perceiving, learning, or problem solving.

2. Abilities are intellectual capabilities (e.g., verbal comprehension) that are general and pervasive to the performance of many tasks.

3. Aptitudes are indices (e.g., mathematical or mechanical aptitude) used to select personnel to perform tasks that demand specific skills and to find the right person for a certain job or school.

Subjects

The subjects were right-handed, male, Caucasian recruits (N=50) from the Naval Training Center, San Diego, who were undergoing basic enlisted military instruction. Audition and vision of the subjects tested normal.

Cognitive Characteristics Measured

The cognitive characteristics measured in the study are reported in Table 1. The six cognitive style and three ability tests were administered to each subject counterbalanced with the ERP recordings. Scores for the two aptitude tests were obtained from Navy personnel records.

Instrumentation

Data were acquired on a field-portable computer system that included a Data General NOVA 2/10 central processing unit (CPU, 32K memory); a dual-drive floppy disk unit (Advanced Electronics Design, Inc., Model 2500); an optically isolated and multiplexing EEG unit with band pass set for 0.2-30 Hz; and a videographic display unit, integrated into the CPU, that presented visual stimuli to the subjects and displayed the analyzed ERP data. Permanent storage of all video information was obtained from a video hard copy unit (Tektronix Model 4632) (Lewis, 1979, 1980; Lewis & Rimland, 1979, 1980; Lewis, Rimland, & Callaway, 1977).

Stimuli

Visual (V) stimuli were computer-generated black and white checker-board patterns presented over the video monitor (Panasonic 14-inch Model WV 5400). Binocular visual field stimulation was about 9 degrees visual angle. Each check subtended about 17 minutes visual angle. Average background luminance was about 0.3 ftL and target luminance was about 5 ftL. The patterns were presented aperiodically, with interstimulus intervals averaging about 2 seconds (1.0-3.0 seconds).

---

[1]The names of various equipments do not imply any endorsement of these equipments.

Table 1

Cognitive Characteristics Measured in this Research

Cognitive Characteristic	Description	Measurement Instrument
Field-independence vs. Field-dependence (FLD)	Analytical vs. global orientation	Hidden Figures Test, Part I (Ekstrom, French, Harman & Dermen, 1976)
Conceptualizing Style (CON)	Span of conceptual category	Clayton-Jackson Object Sorting Test (Clayton & Jackson, 1961)
Reflectiveness-Impulsiveness (REFL)	Deliberation vs. impulse	Impulsivity Subscale from Personality Research Test, Form E (Jackson, 1974)
Tolerance of Ambiguity (TOL)	Inclined to accept complex issues	Tolerance of Ambiguity Scale from Self-Other Test, Form C (Rydell & Rosen, 1966)
Category Width (CATW)	Consistency of cognitive range	Category Width Scale (Pettigrew, 1958)
Cognitive Complexity (COG)	Multidimensional perceptions of the environment	Group Version of Role Construct Repertory Test (Bieri, Atkins, Briar, Leaman, Miller, & Tripodi, 1966)
Verbal Comprehension (VERB)	Understanding the English language	Vocabulary Test II (Ekstrom et al., 1976)
Visualization (SPA)	Manipulating spatial patterns	Surface Development Test (Ekstrom et al., 1976)
Logical Reasoning (LOG)	Deducing from premise to conclusion	Nonsense Syllogisms Test, Part I (Ekstrom et al., 1976)
General Aptitude (AFQT)	Comprehending language, solving arithmetic problems, and visualizing objects in space	Word Knowledge Subtest, Arithmetic Reasoning Subtest, and Space Perception Subtest, Armed Services Vocational Aptitude Battery
Reading Comprehension (RGL)	Understanding English words and prose passages	Gates-MacGinitie Reading Test, Level D, Form 1 (Gates & MacGinitie, 1965)

Auditory (A) clicks were presented binaurally over headphones (Sennheiser Model 424X) aperiodically about every 2 seconds (1.0-3.0 second interstimulus intervals). Click intensity was aout 65 dB (A) (Bruel and Kjaer Impulse Sound Level Meter, Model 2209, One-Third Octave Filter Set, Model 1616). Headphone leads were shielded to minimize click artifacts.

Biomodal (B) presentation included simultaneous presentation of the visual and auditory stimuli. These stimuli were presented aperiodically about every 2 seconds (1.0-3.0 seconds).

During all recording periods, white noise was used for masking. It was presented to the subjects through the headphones and via a speaker in the sound chamber at a level of approximately 50 db (A).

Procedure

Recording Sites

Eight channels of visual, auditory, and bimodal ERP data were acquired from four pairs of homologous sites, as shown in Figure 1. Sites F3 and F4 are over the frontal brain region, an association area; sites T3 and T4 are over the temporal region, a primary auditory reception area where many visual and auditory nerves interconnect; sites P3 and P4 are over the parietal region, a primary association area; and sites O1 and O2 are over the occipital region, a primary visual reception area (Jasper, 1958). Ground was at Pz in the mid-parietal area. Sites designated by odd numbers denote left hemisphere locations; and those designated by even numbers, right hemisphere locations.

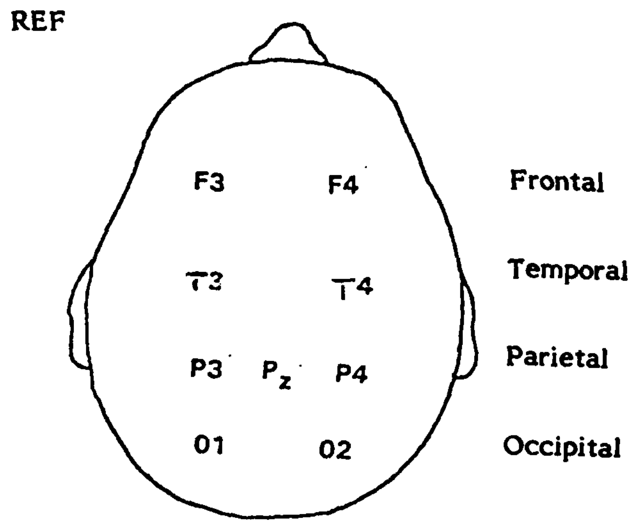


Figure 1. Electrode site montage.

Electrodes

The subjects were prepared for recording after they had received brief instruction. They completed a brief background questionnaire and signed a privacy act and volunteer consent form. An elastic helmet (Lycra) fitted with plastic holders for the electrodes was

placed on the subject's head. Each subject's hair was parted and scalp cleaned with an alcohol-impregnated cotton swab that was placed through the holders. Electrode cream was placed down the holders and rubbed into the scalp. The electrodes were Beckman miniatures (11 mm) with a clear plastic extension tube (38 mm long) attached and filled with electrolytic solution. A small sponge (microcell foam) soaked with electrolyte held the solution in the tube and made contact with the electrode paste on the scalp. The extension tube not only held the electrode in place but also minimized the slow potential drift due to scalp temperature change that would have otherwise been picked up at the recording site. A Beckman mini-electrode fitted with a standard two-sided adhesive wafer served as a reference electrode on the nose.

The helmet and all 10 electrodes could be attached in 6-8 minutes with impedance readings of 2-3K ohms. After all electrodes were in place, the subjects were instructed to observe their real-time EEG activity on the oscilloscope display. They were then instructed to move their jaws, eyebrows, etc. so that they could observe how muscle artifacts could contaminate the ERP data. The subject was then seated in a sound chamber in alignment with the video monitor. A hand-held switch allowed the subject to suspend all stimulus presentation and analysis operations to eliminate artifact. Additional artifact rejection was available by the console operator prior to storing the data.

ERP Data

The visual and auditory ERP data were retrieved from a floppy diskette and the required computations were performed. The data were then displayed on the video monitor and hard copies were obtained. Bimodal ERP data were also computed and displayed in a similar manner.

Eight channels of visual and auditory ERP data are overlaid in Figure 2. Root mean square (RMS) and standard deviation (SD) amplitude values are presented, along with the waveform mean values for the half-second post-stimulus epoch (533 msec). SD amplitude values (in microvolts (μV)) are normalized (waveform mean set to zero) RMS values (in μV). For all analyses, only SD amplitude values (in μV) were used. Prestimulus waveforms (133 msec) were also recorded and displayed for each channel. Calibration, polarity, DC offset, time base, and other descriptive information were also displayed. The waveforms in the left column were derived from the left hemisphere (LH). The waveforms from top to bottom were from the front to the back of the head at frontal, temporal, parietal, and occipital sites (F3, T3, P3, O1). Right hemisphere (RH) ERP data from sites F4, T4, P4, and O2 were represented in the right column.

In addition to the directly recorded ERP amplitudes, two indices were derived to reflect different hypothesized properties of brain behavior. First, in order to assess the relative functioning between the hemispheres, ERP asymmetry measures were examined between homologous electrode sites. An asymmetry index was defined as the right minus left hemisphere amplitude (RH-LH) for a specific brain area. If this expression is positive (negative), then there is a decrease in activity at the left (right) hemisphere site, which indicates increased information processing within that particular location. Second, in order to appraise sensory interaction and its effects on information processing, the relationship between independent single modality presentations (visual or auditory) and the joint bimodal presentation (simultaneous stimulation of visual checkerboard patterns and auditory clicks) was determined. A sensory interaction index was defined as BERP-(VERP + AERP) (Lewis & Froning, 1981; Lewis, Federico, Froning & Calder, 1981). If the result of this expression is positive, then bimodal stimulation produces a greater magnitude response than the sum of separate visual or auditory stimulation. This indicates excitatory or facilitory activity in the brain's nervous system. If the expression

is negative, then attenuated activity occurs in the nervous system when auditory stimulation is presented at the same time as visual stimulation.

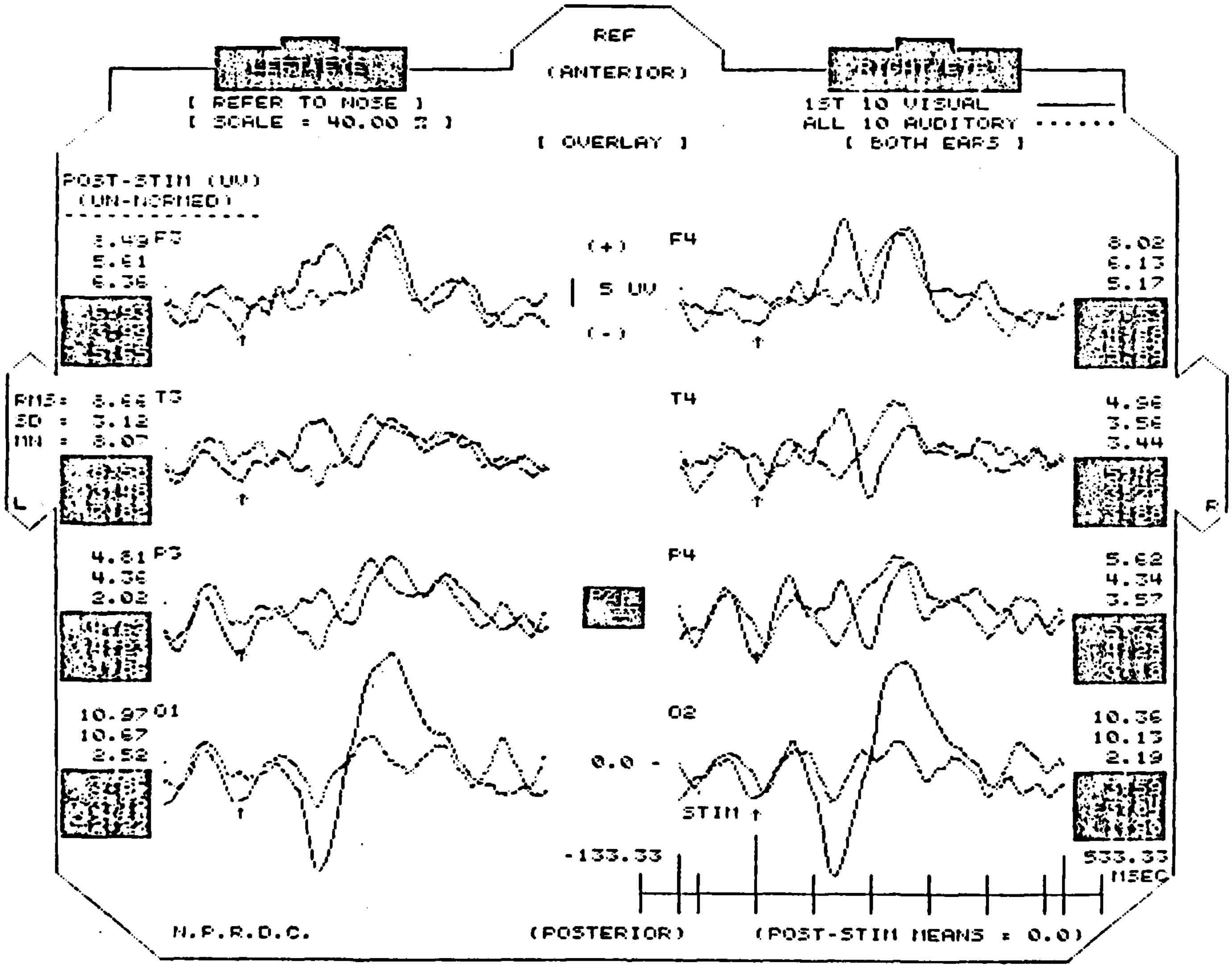


Figure 2. Sample VERP and AERP data. The left column of data is from the left hemisphere; and the right column, from the right hemisphere. From top to bottom, the records are from the frontal, temporal, parietal, and occipital regions.

Statistical Analyses

The relationships between visual, auditory, and bimodal ERPs, as well as those between asymmetry measures, sensory interaction indices, and cognitive characteristics, were exmained by conducting product-moment and canonical correlational analyses. Canonical analysis (Cooley & Lohnes, 1962) derives a linear combination for each set of cognitive characteristics and ERPs such that it maximizes the correlation between them. Instead of computing the correlation between two univariate variables, it computes the correlation between two linear combinations--principal components--of multivariate variables. The absolute values of the weights of the variables indicate their relative contributions or importance to the respective linear combinations or canonical variates. A principal-factor analysis without iteration was also computed for the cognitive characteristics together with only the asymmetry ERPs to determine the independent dimensions that account for a considerable amount of the underlying variability of these indices. This initial factor solution was rotated according to the varimax procedure to achieve a simpler structure and a more meaningful pattern. Rules of thumb for achieving the simplest factor structure and more theoretically meaningful factors have been summarized by Harman (1967, p. 98).

RESULTS

Product-moment Correlational Analyses

The descriptive data for cognitive characteristics, ERPs, ERP asymmetries, and sensory interactions are presented in Tables 2, 3, and 4 respectively. As can be seen in Table 3, mean bimodal ERPs (BERPS) were larger than mean visual ERPs (VERPs) or auditory ERPs (AERPs) at the same electrode sites. Mean visual ERPs were larger than auditory ERPs, especially in right hemisphere sites.

The intercorrelation matrices are presented in Tables 5 through 10. As shown, all cognitive characteristics except conceptualizing style (CON) and category width (CATW) were significantly ($p < .05$) associated with at least some ERPs. The significant correlations ranged from -.47 to .43 with many hovering in the .3's. Higher correlations (in the .4's) involve visualization (as measured by the Surface Development Test (SPA)) with ERPs elicited visually in the left parietal and occipital areas as well as with derived indices of (1) sensory interaction in the left frontal region, and (2) the sum of visual and auditory ERP amplitudes in the left parietal and occipital sites.

1. Correlations Between ERPs and Measures of Cognitive Style. Significant correlations between ERPs and cognitive styles presented in Table 5 indicate that:

a. Field-independence vs. field-dependence (FLD) was negatively correlated with auditory ERPs in the right occipital region.

b. Reflectiveness-impulsiveness (REFL) was negatively correlated with visual ERPs in the right occipital area.

c. Tolerance of ambiguity (TOL) was negatively correlated with visual ERPs in the left temporal and right occipital regions.

d. Cognitive complexity (COG) was positively correlated with bimodal ERPs in the right frontal, temporal, and occipital areas.

As can be seen, the right occipital region is repeatedly implicated in some cognitive styles.

Table 2

Descriptive Data for Cognitive Characteristics

Characteristic	$\bar{X}$	SD
Cognitive Style		
FLD	4.40	3.28
CON	11.70	4.18
REFL	5.44	3.84
TOL	5.82	2.26
CATW	30.00	11.13
COG	73.66	21.98
Aptitudes and Abilities		
AFQT	63.50	18.67
RGL	10.59	1.96
VERB	6.74	2.51
SPA	28.34	16.76
LOG	.48	4.02

Note. N equals 50.

Table 3

Descriptive Data for ERPs and ERP Asymmetries

ERP Index / Hemisphere / Electrode Site	Visual ERPs		Auditory ERPs		Bimodal ERPs	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
ERPs						
Left Hemisphere						
Frontal	2.76	1.17	2.64	1.04	4.44	2.04
Temporal	2.23	.84	2.44	.82	3.07	1.43
Parietal	2.82	1.24	2.97	1.02	4.04	1.60
Occipital	3.87	1.47	3.00	.91	4.85	1.54
Right Hemisphere						
Frontal	2.81	1.31	2.68	1.01	4.29	2.02
Temporal	2.60	.95	2.40	.73	3.43	1.46
Parietal	3.07	1.24	2.82	1.04	4.08	1.56
Occipital	3.65	1.16	2.76	.81	4.86	1.60
Asymmetries						
Right Minus Left Hemisphere						
Frontal	.05	.67	.04	.55	-.15	.76
Temporal	.36	.80	-.04	.85	.36	.96
Parietal	.25	.75	-.15	.75	.04	.91
Occipital	-.21	.88	-.24	.64	.01	.96

Note. N equals 50. $\bar{X}$ values are in standard deviation microvolts.

Table 4

Descriptive Data for Sensory Interactions

ERP Index	Left Hemisphere		Right Hemisphere	
Electrode Site	$\bar{X}$	SD	$\bar{X}$	SD
Sum				
Frontal	5.40	1.96	5.49	1.91
Temporal	4.68	1.41	5.00	1.45
Parietal	5.79	1.99	5.88	2.00
Occipital	6.86	1.98	6.15	2.43
Interaction				
Frontal	-0.96	2.01	-1.21	2.01
Temporal	-1.61	1.46	-1.57	1.25
Parietal	-1.75	1.54	-1.81	1.42
Occipital	-2.01	1.71	-1.55	1.50

Note. N equals 50. $\bar{X}$ values are in standard deviation microvolts. Sum equals VERPs plus AERPs. Interaction equals [BERP - (VERP + AERP)].

Table 5

Correlations Between ERPs and Measures of Cognitive Style

ERP Mode / Hemisphere / Electrode Site	Cognitive Style Measures: FLD	CON	REFL	TOL	CATW	COG
Visual ERPs						
Left Hemisphere						
Frontal	.09	-.11	-.20	-.13	.06	-.07
Temporal	.18	.05	-.17	-.31*	.07	.02
Parietal	.02	-.22	-.21	-.21	.07	-.13
Occipital	-.12	-.13	-.27	-.30	-.10	.05
Right Hemisphere						
Frontal	.17	-.04	-.08	-.14	.13	-.04
Temporal	.12	.06	-.16	-.18	.06	.05
Parietal	.11	-.13	-.20	-.23	.04	-.06
Occipital	-.10	-.05	-.39**	-.30*	-.13	.06
Auditory ERPs						
Left Hemisphere						
Frontal	.04	-.11	-.18	.05	-.10	-.12
Temporal	.06	-.02	-.09	.03	.04	.06
Parietal	-.03	-.08	-.05	.06	.05	-.04
Occipital	-.32*	-.19	-.03	-.19	-.03	.08
Right Hemisphere						
Frontal	-.02	-.18	-.16	.12	-.08	-.10
Temporal	-.00	-.18	-.08	.04	-.09	.14
Parietal	.05	-.24	-.00	.06	-.06	-.03
Occipital	-.07	-.16	.00	-.12	-.15	-.02
Bimodal ERPs						
Left Hemisphere						
Frontal	.18	.13	-.04	-.10	.15	.17
Temporal	.16	.20	.04	-.18	.11	.27
Parietal	.09	.00	-.04	.01	.10	.09
Occipital	.00	-.05	.01	-.22	-.20	.24
Right Hemisphere						
Frontal	.18	.13	-.03	-.15	.13	.29*
Temporal	.17	.16	-.07	-.18	.06	.35*
Parietal	.13	-.09	-.01	-.09	-.06	.20
Occipital	.05	.05	-.06	-.21	-.24	.31*

*$r(48) \geq .28$; $p < .05$.
**$r(48) \geq .36$; $p < .01$.

Table 6

Correlations Between ERPs and Measures of Aptitude and Ability

ERP Mode / Hemisphere / Electrode Site	Aptitude and Ability Measures				
	AFQT	RGL	VERB	SPA	LOG
Visual ERPs					
Left Hemisphere					
Frontal	-.26	-.10	-.25	-.24	-.15
Temporal	-.18	-.21	-.12	-.26	-.14
Parietal	-.27	-.17	-.09	-.45**	-.10
Occipital	-.27	-.16	-.17	-.43**	-.07
Right Hemisphere					
Frontal	-.15	-.27	-.24	-.26	-.11
Temporal	-.18	-.43**	-.21	-.30*	-.16
Parietal	-.23	-.22	-.10	-.36*	-.12
Occipital	-.21	-.18	-.08	-.33*	-.16
Auditory ERPs					
Left Hemisphere					
Frontal	-.23	-.08	-.18	-.23	-.35*
Temporal	-.23	-.11	-.12	-.24	-.15
Parietal	-.11	-.14	-.02	-.24	.02
Occipital	-.22	-.10	-.07	-.33*	.11
Right Hemisphere					
Frontal	-.22	.02	-.09	-.15	-.35*
Temporal	-.36**	-.20	-.31*	-.18	-.26
Parietal	-.24	-.30*	-.11	-.25	.03
Occipital	-.06	-.17	-.09	-.18	.10
Bimodal ERPs					
Left Hemisphere					
Frontal	.06	.03	-.20	.17	-.02
Temporal	-.05	-.04	-.24	.02	-.06
Parietal	-.13	-.10	-.11	-.16	.00
Occipital	-.23	-.08	-.13	-.19	-.17
Right Hemisphere					
Frontal	-.04	-.06	-.28*	.10	-.06
Temporal	-.07	-.16	-.19	.03	-.08
Parietal	-.25	-.13	-.05	-.19	-.08
Occipital	-.09	.00	-.00	-.09	-.14

*$r(48) \geq .28$; $p < .05$.
**$r(48) \geq .36$; $p < .01$.

Table 7

Correlations Between ERP Asymmetries and Measures of Cognitive Style

ERP Mode Electrode Site	Cognitive Style Measures FLD	CON	REFL	TOL	CATW	COG
Visual ERPs						
Frontal	.18	.12	.19	-.05	.14	.04
Temporal	-.04	.03	-.00	.11	-.01	.03
Parietal	.16	.15	.03	-.03	-.05	.11
Occipital	.07	.16	-.06	.11	-.01	.00
Auditory ERPs						
Frontal	-.12	-.13	.06	.11	.04	.03
Temporal	-.07	-.14	.02	.00	-.11	.06
Parietal	.11	-.23	.07	.01	-.15	.00
Occipital	.36**	.06	.04	.12	-.15	-.14
Bimodal ERPs						
Frontal	-.00	-.01	.02	-.13	-.06	.31*
Temporal	.03	-.05	-.17	-.01	-.08	.14
Parietal	.08	-.15	.05	-.19	-.27	.18
Occipital	.07	.16	-.12	.00	-.07	.14

*$r(48) \geq .28$; $p < .05$.
**$r(48) \geq .36$; $p < .01$.

Table 8

Correlations Between ERP Asymmetries and Measures of Aptitude and Ability

ERP Mode Electrode Site	Aptitude and Ability Measures AFQT	RGL	VERB	SPA	LOG
Visual ERPs					
Frontal	.16	-.34*	-.03	-.08	.06
Temporal	-.03	-.29*	-.12	-.08	-.05
Parietal	.06	-.08	-.02	.15	-.03
Occipital	.18	.02	.19	.28*	-.09
Auditory ERPs					
Frontal	.03	.20	.17	.16	.01
Temporal	-.08	-.06	-.15	.08	-.08
Parietal	-.18	-.22	-.12	-.02	.01
Occipital	.23	-.07	-.01	.24	-.02
Bimodal ERPs					
Frontal	-.26	-.26	-.24	-.18	-.09
Temporal	-.04	-.18	.07	.01	-.05
Parietal	-.20	-.05	.10	-.06	-.14
Occipital	.22	.13	.21	.17	.04

$*r(48) \geq .28$; $p < .05$.
$**r(48) \geq .36$; $p < .01$.

Table 9

Correlations Between Sensory Interactions and Measures of Cognitive Style

ERP Mode / Hemisphere / Electrode Site	Cognitive Style Measures					
	FLD	CON	REFL	TOL	CATW	COG
Sum						
Left Hemisphere						
Frontal	.08	-.12	-.22	-.05	-.01	-.10
Temporal	.14	.02	-.16	-.16	.07	.05
Parietal	-.00	-.18	-.16	-.10	.07	-.10
Occipital	-.24	-.19	-.21	-.31*	-.09	.07
Right Hemisphere						
Frontal	.11	-.12	-.14	-.03	.05	-.08
Temporal	.07	-.05	-.14	-.10	-.00	.10
Parietal	.10	-.21	-.12	-.11	-.01	-.06
Occipital	-.16	.04	-.34*	-.38**	-.06	.12
Interaction						
Left Hemisphere						
Frontal	.11	.26	.17	-.06	.17	.28*
Temporal	.02	.18	.19	-.01	.04	.21
Parietal	.10	.23	.16	.14	.01	.22
Occipital	.28*	.17	.26	.17	-.08	.13
Right Hemisphere						
Frontal	.08	.25	.10	-.12	.08	.37**
Temporal	.11	.25	.08	-.09	.07	.30*
Parietal	.01	.20	.16	.05	-.05	.30*
Occipital	.17	.18	.24	.08	-.08	.30*

Note. Sum equals VERPs plus AERPs. Interaction equals [BERP - (VERP + AERP)].

*$r(48) \geq .28$; $p < .05$.
**$r(48) \geq .36$; $p < .05$.

Table 10

Correlations Between Sensory Interactions and Measures of Aptitude and Ability

ERP Mode Hemisphere Electrode Site	Aptitude and Ability Measures				
	AFQT	RGL	VERB	SPA	LOG
Sum					
Left Hemisphere					
Frontal	-.28*	-.11	-.24	-.27	-.28*
Temporal	-.24	-.19	-.14	-.30*	-.17
Parietal	-.23	-.18	-.07	-.40**	-.05
Occipital	-.30*	-.16	-.16	-.47**	-.01
Right Hemisphere					
Frontal	-.22	-.17	-.21	-.25	-.26
Temporal	-.30*	-.38**	-.30*	-.30*	-.24
Parietal	-.27	-.29*	.12	.35*	-.06
Occipital	-.13	-.09	-.05	-.19	-.06
Interaction					
Left Hemisphere					
Frontal	.33*	.14	.04	.43**	.24
Temporal	.18	.14	-.10	.31*	.11
Parietal	.15	.12	-.02	.36**	.06
Occipital	.14	.12	.07	.37**	-.14
Right Hemisphere					
Frontal	.17	.10	-.08	.34*	.19
Temporal	.26	.25	.12	.37**	.18
Parietal	.10	.26	.11	.28*	-.01
Occipital	.09	.23	.10	.26	-.08

*$r(48) \geq .28$; $p < .05$.
**$r(48) \geq .36$; $p < .01$.

2. Correlations Between ERPs and Measures of Aptitude and Ability. Significant correlations in Table 6 reveal that:

a. General aptitude (as measured by the Armed Forces Qualification Test (AFQT)) was negatively correlated with auditory ERPs in the right temporal area.

b. Reading comprehension (RGL) was negatively correlated with visual ERPs in the right temporal region and auditory ERPs in the right parietal region.

c. Verbal comprehension (VERB) was negatively correlated with auditory ERPs in the right temporal area and bimodal ERPs in the right frontal area.

d. SPA was negatively correlated with visual ERPs in the left and right parietal and occipital sites as well as the right temporal site. It was also negatively associated with auditory ERPs in the left occipital area.

e. Logical reasoning (LOG) was negatively correlated with auditory ERPs in the left and right frontal regions.

3. Correlations Between ERP Asymmetries and Measures of Cognitive Style. Table 7 indicates that there were only two significant correlations between ERP asymmetries and measures of cognitive style:

a. FLD was positively correlated with auditorily-elicited asymmetry at the occipital areas.

b. COG was positively correlated with bimodally-evoked ERP asymmetry at the frontal regions.

4. Correlations Between ERP Asymmetries and Measures of Aptitude and Ability. There are only three significant correlations reported in Table 8 between ERP asymmetries and measures of aptitude and ability:

a. RGL was negatively correlated with visual ERP asymmetries in the frontal and temporal sites.

b. SPA was positively correlated with visual ERP asymmetry in the occipital area.

5. Correlations Between Sensory Interactions and Measures of Cognitive Style. Table 9 reveals that:

a. REFL was significantly negatively correlated with the sum of visual and auditory ERPs in the right occipital region.

b. TOL was significantly negatively correlated with the sums of visual and auditory ERPs in the left and right occipital areas.

c. COG was significantly positively correlated with sensory interaction indices for the right hemisphere sites (frontal, temporal, parietal, and occipital) and the left frontal site.

6. Correlations Between Sensory Interactions and Measures of Aptitude and Ability. The significant correlations in Table 10 suggest that:

a. AFQT was negatively correlated with sums of visual and auditory ERPs in the left frontal and occipital and right temporal regions. It was also positively correlated with the index of sensory interaction for the left frontal area.

b. RGL was negatively correlated with the sum of visual and auditory ERPs in the right temporal and parietal regions.

c. VERB was negatively correlated with the sum of visual and auditory ERPs in the right temporal site.

d. SPA was negatively correlated with the sum of visual and auditory ERPs in the left and right temporal and parietal regions and left occipital region. It was also positively correlated with indices of sensory interaction in the left (frontal, temporal, parietal, and occipital) and right (frontal, temporal, and parietal) hemispheres.

e. LOG was negatively correlated with the sum of visual and auditory ERPs in the left frontal area.

Canonical Correlational Analyses

Table 11 summarizes and highlights the significant canonical analyses between all the cognitive characteristics and some ERPs. The significant canonical correlations reveal that some cognitive attributes and ERPs have from 45 to 65 percent variance in common. As can be seen, cognitive characteristics that contribute to the canonical correlations are CON, RGL, AFQT, VERB, FLD, and SPA, as well as ERPs in the right temporal and parietal areas and left frontal and parietal areas. More specifically, Table 11 represents the nature of the significant relationships between all the cognitive attributes and the different ERPs. The variables that contribute to these linear combinations (canonical variates) are listed in the order of their importance according to the relative size of the absolute values of their canonical weights. Spotlighting the significant canonical correlations between cognitive characteristics and ERPs, Table 11 discloses the following relationships:

1. Visual ERPs from the right hemisphere indicate that RGL, FLD, and CON are correlated with parietal and temporal regions.

2. Visual ERPs from the left hemisphere indicate that SPA, AFQT, and CON are associated with activity in the parietal and frontal areas.

3. Bimodal ERPs from the right hemisphere indicate that VERB, AFQT, and CON are correlated with temporal and parietal activity.

4. Bimodal ERPs from both hemispheres indicate that VERB, RGL, and CON are associated with right temporal and parietal areas.

5. Visual plus auditory ERPs from the right hemisphere indicate that RGL, FLD, and CON are correlated with temporal and parietal activity.

Factor Analysis

There were 52 ERP measures and 11 cognitive characteristics, but only 50 subjects upon which to base a principal-factor solution with varimax rotation. Consequently, if all ERP measures had been used as input data, then the derived factors would have been very unstable and indeterminant because of the large number of variables relative to the small number of subjects. The results of such analyses would have been only suggestive at the very best. Also, this situation would have violated accepted criteria for selecting the number of subjects for factor analysis. Some researchers (e.g., Cattell, 1966) suggest that the proper ratio of subjects to variables is from 2:1 to as high as 5:1. With small ratios, common factor variance would be inflated, resulting in the extraction of more factors than necessary, and at the same time upsetting simple structure rotation and factor recognition (Guertin & Bailey, 1970). Under these circumstances, factor analyses would have been questionable, if not meaningless. Therefore, instead of using all 52 ERP measures, only the 12 asymmetry indices were used as inputs to the factor analysis. When these were added to the 11 cognitive characteristics, the ratio of subjects to variables was 50:23--slightly better than the 2:1 lower bound mentioned in Cattel's guidelines. Also, Rummel (1970), when ruminating over the proper ratio of the number of cases to

Table 11

Summary of Significant Canonical Analysis Between Cognitive Characteristics and Event-related Potentials

Canonical Analysis No.	Number of Significant Canonical Variate Pairs	ERP Measures	Significance of Canonical Correlation						Abbreviated Canonical Variate Pairs[a]	
			R_c	R_c^2	Λ	χ^2	d.f.	p	Cognitive Characteristics	Event-related Potentials[b]
1	1	VERPs (RH)	.72	.52	.19	68.14	44	.011	.74FLD - .70CON + 1.07RGL	-1.37VRT4 + 1.42VRP4
2	1	VERPs (LH)	.67	.45	.25	57.51	44	.083	-.54CON - 1.10SPA + .60AFQT	-57VLF3 + 1.22VLP3
3	1	BERPs (RH)	.74	.55	.22	62.62	44	.034	.41CON - .78VERB + .69AFQT	1.39BRT4 - 1.36BRP4
4	1	BERPs (BH)	.81	.65	.06	107.19	88	.080	.58CON - .86VERB + .70RGL	1.36BRT4 - 1.83BRP4
5	1	Sum[c] (RH)	.70	.50	.20	66.34	44	.016	-.59FLD + .53CON - .72RGL	1.73VAT4 - 1.74VAP4

[a]Only those cognitive characteristics and ERPs having canonical weights or loadings whose absolute values are equal to or greater than .40 are tabled.

[b]<u>Legend</u>

A = auditory ERPs
B = bimodal ERPs
F = frontal lobe
LH = left hemisphere
O = occipital lobe
P = parietal lobe
RH = right hemisphere
T = temporal lobe
V = visual ERPs
VA = visual + auditory ERPs
BH = both hemispheres

[c]Sum equals VERPs plus AERPs.

variables for factor analysis, makes the distinction between interest in describing data and inferencing from sample results to population factors. In the first case, Rummel maintains that a factor analysis will produce an adequate data description even if the number of variables is larger than cases. In the second case, he asserts that a factor analysis will yield a valid inference from sample to universal factors only if the number of cases is larger than variables. Rummel (1970, p. 220) mentions that "determining what the minimum allowable ratio of cases to variables is a matter of research taste." In this study, the prime interest was in describing the variability common to brain ERPs and cognitive attributes--not in generalizing to universal factors. Consequently, it seemed reasonable as well as "tasteful" to employ 23 variables (12 asymmetry measures and 11 cognitive attributes) and 50 cases for factor analysis.

Visual, auditory, and bimodal asymmetry measures were factor analyzed together with the cognitive characteristics indices because lateral hemispheric differences may be related to dominant modes of information processing that individuals typically employ when perceiving, learning, or problem solving. By factor analyzing brain asymmetry measures together with some cognitive styles, abilities, and aptitudes, the independent dimensions that account for much of the underlying variability of these indices can be identified. This would be useful for establishing the construct validity of brain ERPs as indicators of human cognitive processing.

Rotated-factor Solution

To achieve a simpler structure and a more meaningful pattern, the principal-factor solution was rotated according to the varimax procedure. The results of this rotation for the brain asymmetry and cognitive attributes data are listed in Table 12. Eight significant factors accounted for 74.4 percent of the variance. The terminal factors, in order of diminishing percentages of the variance accounted for, are described below.

1. Factor 1 was characterized by auditory and bimodal asymmetries in the frontal, temporal, and parietal areas (11.8% of the variance).

2. Factor 2 was characterized by visual and bimodal asymmetries in the temporal and parietal areas (11.2% of the variance).

3. Factor 3 was a cognitive dimension characterized by VERB, AFQT, LOG, REFL, SPA, and RGL (10.6% of the variance).

4. Factor 4 was characterized by visual and bimodal asymmetries in the occipital areas (8.8% of the variance).

5. Factor 5 was characterized primarily by TOL, CATW, AFQT, SPA, and LOG and secondarily by bimodal asymmetry in the parietal regions (8.3% of the variance).

6. Factor 6 was characterized by visual and bimodal asymmetries in the frontal areas and by RGL (8.2% of the variance).

7. Factor 7 was characterized primarily by auditory asymmetry in the occipital regions and FLD and secondarily by SPA and CATW (8.1% of the variance).

8. Factor 8 was a cognitive dimension characterized by CON, COG, SPA, RGL, and LOG (7.4% of the variance).

Table 12

Varimax-factor Matrix for the Brain Asymmetry Measures and Cognitive Characteristics Data

Measure	Factors 1	2	3	4	5	6	7	8
Visual Asymmetry								
Frontal	.00	.11	.10	.00	.15	.86	.09	.07
Temporal	.01	.81	-.15	.00	.17	.24	.01	-.03
Parietal	.07	.86	.05	.13	-.05	.00	.17	.14
Occipital	.02	.21	.03	.86	.06	-.08	.11	.03
Auditory Asymmetry								
Frontal	.82	-.12	.15	.20	.09	.05	-.13	.02
Temporal	.86	.27	-.12	-.01	.02	.05	.08	-.01
Parietal	.75	.37	-.07	-.21	-.10	.04	.30	-.18
Occipital	.12	.17	-.06	.14	.14	-.01	.77	-.14
Bimodal Asymmetry								
Frontal	.41	.04	-.16	.07	-.15	.67	-.17	.22
Temporal	.36	.70	-.01	.36	-.11	.06	-.03	-.01
Parietal	.48	.57	.12	.15	-.51	-.14	.03	.00
Occipital	.05	.08	.10	.91	-.05	.07	.04	.08
Cognitive Style								
FLD	-.09	.01	.30	.00	-.05	.17	.74	.22
CON	-.26	.08	.22	.08	.13	.04	.12	.74
REFL	.03	-.04	.52	-.26	-.16	.31	.19	-.06
TOL	.10	-.02	.05	.04	.67	-.09	.22	-.08
CATW	-.12	.05	.19	-.08	.61	.19	-.33	-.01
COG	.13	.04	-.25	.03	-.22	.09	-.08	.72
Aptitude and Ability								
AFQT	-.08	-.02	.64	.18	.50	-.10	.28	.18
RGL	.12	-.21	.38	.09	.17	-.58	-.22	.35
VERB	-.02	-.03	.85	.20	.06	-.15	.07	.07
SPA	.13	-.03	.39	.16	.44	-.25	.39	.40
LOG	.00	.02	.61	-.04	.35	.01	-.19	-.35
Associated Eigenvalue	2.71	2.59	2.43	2.03	1.91	1.89	1.86	1.70
% Variance Accounted for	11.78	11.24	10.58	8.81	8.32	8.21	8.10	7.37
Cumulated % Variance	11.78	23.02	33.60	42.41	50.73	58.94	67.04	74.41

Note. Only factors with associated eigenvalues greater than or equal to 1.0 are tabulated. This minimum eigenvalue criterion may ensure that only factors accounting for at least the amount of total variance of a single variable are significant.

Factors 1, 2, and 4, defined primarily by brain asymmetry measures, jointly accounted for approximately 32 percent of the variance. Factors 3 and 8, characterized chiefly by psychometric measures of abilities, aptitudes, and cognitive styles, together accounted for about 18 percent of the variance. Factors 5, 6, and 7, specified by brain asymmetry and cognitive psychometric measures, accounted for approximately 24 percent of the variance. These statistics imply that a major portion of the variability in the data was attributed to brain asymmetry measures either acting independently (32%) or interactively with cognitive measures (24%). These latter factors, 5, 6, and 7, suggest that some ERPs and cognitive characteristics contribute to or define the same underlying independent dimensions. That is, they weight the same factors, implying that they are related.

DISCUSSION AND CONCLUSIONS

Highlighting only a few of the significant results of the product-moment and canonical correlational analyses and the varimax rotated factor solution, it appears that complex information processing may be related to brain electrical activity evoked visually, auditorily, or bimodally in the left and right hemispheres. This is evident from some of the results of the product-moment and canonical correlations as well as the varimax rotation. Some of the product-moment correlations in Table 6, though only slight at best, showed that complicated cognitive attributes (i.e., AFQT, RGL, and VERB) are related to visual, auditory, and/or bimodal ERPs in the right temporal and parietal and left frontal areas. Two of the significant correlations in Table 8 established that visual ERP asymmetries in the frontal and temporal regions are associated with RGL. In Table 10 the derived index consisting of visual plus auditory ERP amplitudes implicated the right temporal site in AFQT, RGL, and VERB performance. This index for the right parietal area was significantly associated with RGL, and for the left frontal area, AFQT. Some of the correlations reported in Tables 6 and 10 suggest that the left and right parietal and occipital regions are especially involved in SPA performance. Other correlations using interaction indices implied that sensory facilitation at practically all eight sites from both hemispheres contribute substantially to SPA performance. Also, it is interesting to note that auditory ERPs in the left and right frontal regions were associated with LOG.

The canonical correlations presented in Table 11 also revealed, among other things, that AFQT, RGL, VERB, and SPA were associated with visual, bimodal, and/or the index of visual plus auditory ERPs in the right temporal and parietal areas and/or left frontal and parietal areas. These cognitive attributes and brain regions, as established by the canonical correlations, were found to have anywhere from 45 to 65 percent variance in common. The shared variances between brain ERPs and cognitive characteristics produced by the canonical correlations were obviously much larger than those produced by the product-moment correlations. The latter only ranged approximately between 10 and 20 percent.

Even some of the findings of the varimax-rotated factor solution suggest that AFQT, RGL, and SPA are associated with bimodal ERPs in the parietal and frontal areas. Specifically, Factor 5 (8.3% of the variance) implies that AFQT and SPA are related to bimodal asymmetry in the parietal regions; Factor 6 (8.2% of the variance), that RGL is related to bimodal asymmetry in the frontal areas, and Factor 7 (8.1% of the variance), that SPA is related to auditory asymmetry in the occipital sites.

The spotlighted results of the product-moment, canonical, and factor analyses seem to indicate that complex information processing, as indexed by AFQT, RGL, VERB, and

SPA, is associated with brain activity in the frontal, temporal, parietal, and occipital regions. The AFQT is based on three subtests covering word knowledge, arithmetic reasoning, and space perception. Each of these component tests in turn represents a particular type of complicated processing (i.e., comprehending language, solving arithmetic problems, and visualizing objects in space). RGL also consists of separate, though highly related, components having to do with understanding English words and prose passages. Conducting analyses of the cognitive constituents of AFQT, RGL, VERB, and SPA would certainly further reveal the nature and complexity of the information processing involved in these subtasks. For example, Frederiksen (1980) and Hunt (1980) have conducted and discussed componential analyses of reading skill and verbal comprehension respectively. They have demonstrated that these behaviors consist of many complicated information-processing components such as attending, encoding, storing, retrieving, and decoding.

The performances required by the AFQT, VERB, and SPA measures and the results of the correlational and factor analyses disclose that brain activity elicited in the frontal, temporal, parietal, and occipital areas may be related to complex information processing. The associations established between AFQT, RGL, VERB, and SPA and visual, auditory, and bimodal ERPs should not, however, overshadow the importance of the many other significant relationships uncovered by this study.

With respect to cognitive styles, the most notable findings of the product-moment correlations reported in Tables 5, 7, and 9 were the repeated negative associations of visual and auditory ERPs in the right occipital region with cognitive styles (i.e., FLD, REFL, and TOL). Other salient results concerning cognitive styles were the positive correlations established between bimodal ERPs in the right frontal, temporal, and occipital areas, as well as ERP sensory interaction indices in the right hemisphere, and COG. These findings suggest that individuals who are more field-independent, impulsive, and tolerant of ambiguous situations engage the right occipital region in information processing, as indicated by decreases in ERP amplitudes at that site.

Since higher total scores in COG indicate less cognitively complex persons, it appears that these individuals, who are little inclined to perceive the environment in a multidimensional manner, engage the right hemisphere less, as demonstrated by lack of attenuation of bimodal ERP amplitudes in these areas. Paradoxically, it appears that less cognitively complex individuals manifest some sort of facilitation in the right hemisphere as reflected by the derived sensory interaction index. Also, ironically, bimodal ERP asymmetry in the frontals seems to be related to less cognitive complexity, whereas auditory ERP asymmetry is associated with more field independence.

Some of the results of the varimax rotation implicated bimodal asymmetry in the parietals in TOL. This cognitive characteristic had also been associated with left and right occipital regions by some of the significant product-moment correlations. It appears then that TOL is negatively associated with electrical activity in the back of the brain, the parietal and occipital areas. Being able to tolerate ambiguous situations and ideas has been customarily associated with intelligence, which has in turn been related to the left parietal region (Lewis, Rimland, & Callaway, 1977).

Considering aptitudes and abilities, the product-moment correlations suggested many interesting relationships. Spotlighting only some of these, visual ERPs revealed that the right temporal region was negatively related to RGL and SPA, and the left and right parietal and occipital regions were negatively related to SPA. A few of these findings somewhat substantiated Lewis and Rimland's (1976) results that left parietal amplitudes elicited by visual stimuli were associated with predicting success in a Navy remedial

reading program. Lewis et al. (1977) also suggested that left parietal amplitudes triggered by visual stimuli are related to AFQT. Lewis and Froning (1981) demonstrated that the left parietal and right temporal areas discriminated between high and low reading groups using visual ERPs. Their investigation, together with the present study, indicated the importance of these sites for reading skill.

Some of the findings of this research regarding auditory ERPs suggested the importance of the right temporal region for AFQT and VERB, the right parietal region for RGL, and the left and right frontal regions for LOG. With respect to bimodal ERPs, it appeared that the right frontal area is negatively associated with VERB. These associations suggested that not only the front parts of the brain, frontal and temporal areas, but also a back part of the brain, the right parietal area, is implicated in aptitude and ability. This is somewhat similar to the Lewis et al. (1977) finding that asymmetry at the parietal areas significantly distinguished between high and low AFQT groups. It should be pointed out, however, that in this reported study, visual ERP asymmetries in the front part of the brain, the frontal and temporal sites, were negatively correlated with RGL.

AFQT was also found to be positively correlated with the sensory interaction index in the left frontal region, as was SPA with these indices for the left and right hemispheres. These results are somewhat similar to Lewis and Froning's (1981) findings that sensory interaction indices for left and right occipital and right temporal areas separated high and low reading groups. It is interesting to note that, in this present study, there were no significant correlations between right hemisphere sensory interaction indices and AFQT, RGL, and VERB. Left frontal sensory interaction does seem to be related to higher order cognitive functions as assessed by AFQT. Possibly, there is more attenuation in the left than the right frontal region, which would account for the importance of the former over the latter with respect to AFQT. This notion is somewhat supported by Lewis, Federico, Froning, and Calder's (1981) finding that a verbal group, when compared with a spatial group, exhibited greater inhibition in the left hemisphere than in the right due to bimodal stimuli presentation. It is feasible to assume that more activation was occurring in the left hemisphere, the one that is considered to be most involved in verbal processing.

Many of the findings from this present research did not corroborate the results of a number of other studies: Right hemisphere ERP amplitudes and asymmetry measures appear to be directly related to intelligence--but not always (Bigum, Dustman, & Beck, 1970; Galbraith, Gliddon, & Busk, 1970; Perry, McCoy, Cunningham, Falgot, & Street, 1976; Rhodes, Dustman, & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini, & Morganstern, 1971; Shucard & Horn, 1973).

This study's more salient findings were that some ERPs elicited in the frontal, temporal, parietal, and occipital regions were related to abilities and aptitudes: general aptitude, reading and verbal comprehension, and spatial ability, as indexed by AFQT, RGL, VERB, and SPA respectively; and to cognitive styles: field dependence-independence, reflection-impulsivity, tolerance of ambiguity, and cognitive complexity, as indexed by FLD, REFL, TOL, and COG respectively.

According to Snow (1980), Cattell's (1971) crystallized ability, G_c, represents a general dimension of measures that are good predictors of conventional educational achievement or scholastic ability (e.g., verbal, quantitative, vocabulary, reading comprehension, information, mathematical, and prior scholastic achievement). Cattell's (1971) fluid ability, G_f, represents another general dimension of measures that probably represents assembly and control processes necessary to structure adaptive strategies for solving novel and immediate problems (e.g., abstract, spatial, figural, and nonverbal reasoning tests).

In attempting to answer why G_c measures are often better predictors of learning than G_f measures, Snow (1980, p. 37) speculated:

> One reason may be that G_c represents the long-term accumulation of knowledge and skills, organized into functional cognitive systems by prior learning, that are in some sense crystallized as units for use in future learning. Because these are products of past education, and because education is in large part accumulative, transfer relations between past and future learning are assured. The transfer need not be of specific knowledge but rather of organized academic learning skills. Thus G_c may represent prior assemblies of performance processes retrieved as a system and applied new in instructional situations not unlike those experienced in the past, whereas G_f may represent new assembilies of performance processes needed in more extreme adaptations to novel situations. The distinction, then, is better long-term assembly for transfer to familiar new situations versus short-term assembly for transfer to unfamiliar new situations.

It seems reasonable within Snow and Cattell's contexts to consider AFQT, RGL, and VERB measures of G_c; and SPA, FLD, REFL, TOL, and COG measures of G_f. This distinction between G_c and G_f measures suggests that ERPs elicited in the frontal, temporal, and parietal regions of the brain are primarily indicators of crystallized intelligence, and those elicited in occipital regions are primarily indicators of fluid intelligence. Generally, in this study, ERPs evoked in the frontal, temporal, and parietal areas were associated with general aptitude (i.e., comprehending language, solving arithmetic problems) and verbal and reading skill (i.e., understanding English words and prose passages), which are chiefly measures of crystallized intelligence. ERPs evoked in the occipital areas were generally associated with spatial ability (i.e., manipulating spatial patterns), field-dependence-independence (i.e., processing analytically versus globally), reflection-impulsivity (i.e., deliberating versus acting impulsively), tolerance of ambiguity (i.e., inclining to accept complex issues), and cognitive complexity (i.e., perceiving the environment in a multidimensional manner), which are chiefly measures of fluid intelligence.

Neuroanatomical substrates have been identified that contribute some support to this theory. Brodmann's segments 9, 10, 11, and 12 in the frontal lobe of the brain constitute "association" areas. These regions apparently project as well as receive a number of long, primary, association bundles that interconnect the different parts of each hemisphere (Goldman-Rakic & Schwartz, 1982; Grossman, 1967; Peele, 1961). Consequently, it is possible that these areas can readily interact or associate with practically all other segments of the cortex. These numerous interconnections could serve as the neuroanatomical analogue for crystallized intelligence: long-term storage of knowledge and skills, structured into functional cognitive systems by previous experience, established assemblies of performance processes retrieved as a system and used in new instructional situations similar to those of the past. Brodman's segments 17, 18, and 19 in the occipital lobe of the brain constitute cortical centers for vision and visual "association." The numerous interconnections in these brain segments could serve as the neuroanatomical analogue for fluid intelligence: short-term assembly and control processes to structure adaptive strategies for solving novel and immediate problems in unfamiliar situations.

If some ERPs are indeed correlates of crystallized and fluid intelligence, as suggested, then Navy managers who are responsible for developing and evaluating procedures for selecting and classifying incoming personnel, as well as assigning and adapting specific curricula to them, have another possible option. Results obtained from paper-and-pencil tests of ability, aptitude, and achievement are, by their very nature, confounded or intermingled with reading skills of the pesonnel being assessed. It may be feasible to obtain more accurate measures, which are devoid of this confounding, of individuals' crystallized and fluid intelligence by using ERP technology. This would be true especially for those personnel who have a low reading ability that prohibits them from doing as well on paper-and-pencil tests as they might without this handicap.

Some of what must be considered in the decision to employ paper-and-pencil tests versus ERP procedures to evaluate crystallized and fluid intelligence are the incurred costs, expended energy, and time spent involved in each of these two alternative assessment techniques. When this is done, employing ERP technology to estimate the crystallized and fluid intelligence of some individual incoming or on-board personnel seems reasonable and viable at this time in light of cost, labor, and time restraints.

The findings of the research presented in this report:

1. Suggest that ERP procedures can be used to study the relationships between electrical activity in the brain and human cognition.

2. Confirm the possibility of employing brain ERPs for indexing certain cognitive styles, abilities, and aptitudes.

3. Imply that ERPs reflect individual differences in intellectual function.

4. Establish ERP correlates of crystallized and fluid intelligence.

5. Demonstrate the construct validity of brain ERPs as indicators of human congnitive processing.

Several limitations of this research should be noted. The ERP recordings were not obtained at the same time the subjects were taking the written tests. This research should be replicated using a larger subject sample. The assumption was made that cognitive style, ability, and aptitude tests having moderate to high reliability, such as those used in this research, do in fact measure individual differences in information processing.

DIRECTION OF RESEARCH

Since ERPs appear to be valid measures of individual differences in human information processing, especially in crystallized and fluid intelligence, they may provide a basis for developing adaptive instructional techniques. Research is now underway that records ERPs prior to and during the initial learning and subsequent performance of Navy-relevant, real-world, information-processing tasks (e.g., detecting, analyzing, recognizing, and classifying radar signals). While the research subjects are learning and performing these tasks, ERP measures are obtained, along with error patterns, hit-and-miss rates, and student achievement. These learning and performance indices are being related to the ERP measures to determine their possible use for designing adaptive instructional strategies and for predicting student performance.

REFERENCES

American Psychological Association (APA), Standards for educational and psychological tests and manuals, Washington, DC: APA, In, 1966.

Barnet, A. B. EEG and evoked response correlates of mental retardation. Clinical proceedings of the children's hospital, 1971, 27, 250-260.

Barnet, A. B., & Lodge, A. Click evoked EEG responses in normal and developmentally retarded infants. Nature, 1967, 214, 252-255.

Bennett, W. F. Human perception: A network theory approach. Nature, 1968, 220, 1147-1148.

Bieri, J., Atkins, A. L., Briar, S., Leaman, R. L., Miller, H., & Tripodi, T. Clinical and social judgment: The discrimination of behavioral information. New York: John Wiley & Sons, 1966.

Bigum, H. B., Dustman, R. F., & Beck, E. C. Visual and somato-sensory evoked responses from mongoloid and normal children. Electroencephalography and Clinical Neurophysiology, 1970, 28, 576-585.

Bogen, J. E. The other side of the brain, I, II, III, Bulletin of the Los Angeles Neurological Society, 1969, 34, 73-105, 135-162, 191-220.

Buchsbaum, M., & Silverman, J. Averaged evoked response and perception of the vertical. Journal of Experimental Research in Personality, 1970, 4, 79-83.

Callaway, E. Correlations between averaged evoked potentials and measures of intelligence. Archieves of General Psychiatry, 1973, 29, 553-558.

Callaway, E. Brain electrical potentials and individual psychological differences. New York: Grune & Stratton, 1975.

Callaway, E., & Stone, G. C. Evoked response methods for the study of intelligence. Agressologie, 1969, 10, (special number), 535-539.

Cattell, R. B. The meaning and strategic use of factor analysis. In R. B. Cattell (Ed.), Handbook of multivariate experimental psychology. Chicago: Rand McNally & Co., 1966.

Cattell, R. Abilities: Their structure, growth, and action. Boston: Houghton Mifflin, 1971.

Chalke, F. C. R., & Ertl, J. P. Evoked potentials and intelligence. Life Sciences, 1965, 4, 1319-1322.

Clayton, M., & Jackson, D. M. Equivalence range, acquiescence, and over-generalization. Educational and Psychological Measurement, 1961, 21, 371-382.

Cooley, W. W., & Lohnes, P. R. Multivariate procedures for the behavioral sciences. New York: John Wiley & Sons, 1962.

Cronbach, L. J., & Snow, R. E. Aptitude and instructional methods: A handbook for research on interactions. New York: Irvington, 1977.

Dimond, S. J., & Beaumont, J. G. (Eds.). Hemisphere function in the human brain. New York: Wiley, 1974.

Donchin, E. On evoked potentials, cognition, and memory. Science, 1975, 190(4218), 1004-1005.

Donchin, E., & Cohen, L. Averaged evoked potentials and intramodality selective attention. Electroencephalography and Clinical Neurophysiology, 1967, 22(6), 537-546.

Donchin, E., Kubovy, M., Kutas, M., Johnson, R., & Hering, R. Graded changes in evoked response (P300) amplitude as a function of cognitive activity. Perception and Psychophysics, 1973, 14(2), 319-324.

Ekstrom, R. B., French, J. W., Harman, H. H., & Derman, D. Manual for kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service, 1976.

Engel, R., & Fay, W. Visual evoked responses at birth, verbal scores at three years, and IQ at four years. Developmental Medicine and Child Neurology, 1972, 14, 283-289.

Ertl, J. Evoked potentials, neural efficiency, and IQ. In L. D. Proctor (Ed.). Biocybernetics of the central nervous system. Boston: Little and Brow, 1969.

Ertl, J. P. Fourier analysis of evoked potentials and human intelligence. Nature, 1971, 230, 525-526.

Ertl, J. P. IQ evoked responses and Fourier analysis. Nature, 1973, 241, 209-210.

Ertl, J. P., & Schafer, E. W. P. Brain response correlates of psychometric intelligence. Nature, 1969, 223, 421-422.

Federico, P-A. Accommodating instruction to student characteristics: Trends and issues (NPRDC Tech. Rep. 79-1). San Diego: Navy Personnel Research and Development Center, October 1978. (AD-A060 587)

Federico, P-A. Adaptive instruction: Trends and issues. In R. E. Snow, P-A. Federico, & W. E. Montague (Eds.). Conference proceedings: Aptitude, learning, and instruction, Volume I, cognitive process analyses of aptitude (NPRDC/ONR Tech. Rep. 81-5). San Diego: Navy Personnel Research and Development Center, January 1981. (AD-A099 209)

Federico, P-A, & Landis, D. G. Discriminating between failures and graduates in a computer-managed course using measures of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 79-21). San Diego: Navy Personnel Research and Development Center, June 1979. (a) (AD-A070 748)

Federico, P-A., & Landis, D. B. Predicting student performance in a computer-managed course using measures of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 79-30). San Diego: Navy Personnel Research and Development Center, August 1979. (b) (AD-A074 880)

Federico, P-A., & Landis, D. B. Relationships among some measures of cognitive styles, abililities, and aptitudes (NPRDC Tech. Rep. 80-23). San Diego: Navy Personnel Research and Development Center, April 1980. (AD-A090 729)

Frederiksen, J. R. Component skills in reading: Measurement of individual differences through chronometric analysis. In R. E. Snow, P-A. Federico, & W. E. Montague (Eds.), Conference proceedings: Aptitude, learning, and instruction, Volume I. Cognitive process analyses of aptitude (NPRDC/ONR Tech. Rep. 81-5). San Diego: Navy Personnel Research and Development Center, January 1981. (AD-A099 209)

Friedman, M., Guyer-Christie, B., & Tymchuk, A. Cognitive style and specialized hemispheric processing in learning disability. In R. Knights and D. Bakker (Eds.). The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Galbraith, G. C., Gliddon, J. B., & Busk, J. Visual evoked responses in mentally retarded and nonretarded subjects. American Journal of Mental Deficiency, 1970, 75, 341-348.

Galin, D., & Ellis, R. R. Asymmetry in evoked potentials as an index of lateralized cognitive processes: Relation to EEG alpha asymmetry. Neuropsychologia, 1975, 13, 45-50.

Galin, D., & Ornstein, R. Lateral specialization of cognitive mode: An EEG study. Psychophysiology, 1972, 9, 412-418.

Gates, A. I., & MacGinitie, W. H. Gates-MacGinitie Reading Tests. New York: Teachers College Press, 1965.

Goldman-Rakic, P., & Schwartz, M. Interdigitation of contralateral and ipsilateral columnar projections to frontal association cortex in primates. Science, 1982, 216, 755-756.

Grossman, S. P. A textbook of physiological psychology. New York: John Wiley and Sons, 1967.

Gucker, D. K. Correlating visual evoked potentials with psychometric intelligence, variation in technique. Perceptual and Motor Skills, 1973, 37, 189-190.

Guertin, W. H., & Bailey, J. P. Introduction to modern factor analysis. Ann Arbor, MI: Edwards Brothers, Inc., 1970.

Harman, H. H. Modern factor analysis. Chicago: The University of Chicago Press, 1967.

Henderson, N. B., & Engel, R. Neo-natal visual evoked potentials as predictors of psychoeducational tests at age seven. Developmental Psychology, 1974, 10, 269-276.

Horst, R. L., Johnson, R., & Donchin, E. Event-related brain potentials and subjective probability in a learning task. Memory and Cognition, 1980, 8(5), 476-488.

Hunt, E. The foundations of verbal comprehension. In R. E. Snow, P-A. Federico, & W. E. Montague (Eds.), Conference proceedings: Aptitude, learning, and instruction, Volume I. Cognitive process analyses of aptitude. (NPRDC/ONR Tech. Rep. 81-5). San Diego: Navy Personnel Research and Development Center, January 1981. (AD-A099 209)

Israel, J., Chesney, G., Wickens, C., & Donchin, E. P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. Psychophysiology, 1980, 17(3), 259-273.

Israel, J., Wickens, C., Chesney, G., & Donchin, E. The event-related potential as an index of display-monitoring workload. Human Factors, 1980, 22(2), 211-224.

Jackson, D. N. Personality research form manual. Goshen, NY: Research Psychologist Press, Inc., 1974.

Jasper, H. The ten-twenty electrode system of the international federation. Electroencephalography and clinical neurophysiology, 1958, 10, 371-375.

Kinsbourne, M. (Ed.), Asymmetrical function of the brain. New York: Cambridge University Press, 1978.

Knights, R. M., & Bakker, D. J. The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Lewis, G. W. Visual event related potentials of pilots and navigators. In Lehmann, D. & Callaway, E. Human evoked potentials: Applications and problems. New York: Plenum Press, 1979.

Lewis, G. W. Job performance and brain asymmetry: Relevance for physical security personnel. Presented at the Fifth Annual Meeting on the Role of Behavior Science in Physical Security, held 11-12 June 1980 at the National Bureau of Standards, Gaithersburg, Maryland.

Lewis, G. W., Federico, P-A., Froning, J. N., & Calder, M. Event related brain potentials and cognitive processing: Implications for Navy training. (NPRDC Tech. Rep. 82-8). San Diego: Navy Personnel Research and Development Center, October 1981. (AD-A109 019)

Lewis, G. W., & Froning, J. N. Sensory interaction, brain activity, and reading ability in young adults. International Journal of Neuroscience, 1981, 15, 129-140.

Lewis, G. W., & Rimland, B. Psychobiological predictors of success in a navy remedial reading program (NPRDC Tech. Rep. 77-13). San Diego: Navy Personnel Research and Development Center, December 1976. (AD-A037 339)

Lewis, G. W., & Rimland, B. Hemispheric asymmetry as related to pilot and radar intercept officer performance (NPRDC Tech. Rep 79-13). San Diego: Navy Personnel Research and Development Center, March 1979. (AD-A068 087)

Lewis, G. W., & Rimland, B. Psychobiological measures as predictors of sonar operator performance (NPRDC Tech. Rep. 80-26). San Diego: Navy Personnel Research and Development Center, May 1980. (AD-A085 030)

Lewis, G. W., Rimland, B., & Callaway, E. Psychobiological correlates of aptitude among Navy recruits. (NPRDC Tech. Note 77-7). San Diego: Navy Personnel Research and Development Center, February 1977.

Marcus, M. M. The evoked cortical response: A technique for assessing development. California Mental Health Research Digest, 1970, 8, 59-72.

Ornstein, R. E. The psychology of consciousness (2nd Ed.). New York: Harcourt Brace Jovanovich, Inc., 1977.

Osborne, R. T. Heritability estimates for the visual evoked response. Life Sciences, 1970, 9, 481-490.

Peele, T. L. The neuroanatomical basis for clinical neurology (2nd Ed.). New York: McGraw-Hill, 1961.

Perry, N. W., McCoy, J. G., Cunningham, W. R., Falgout, J. C., & Street, W. J. Multivariate visual evoked response correlates of intelligence. Psychophysiology, 1976, 13, 323-329.

Pettigrew, T. F. The measurement and correlates of category width as a cognitive variable. Journal of Personality, 1958, 26, 532-544.

Pizzamiglio, L. Cognitive approach to hemispheric dominance. In R. Knights & D. Bakker (Eds.). The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Ray, W., Morell, M., Frediani, A., & Tucker, D. Sex differences and lateral specialization of hemispheric functioning. Neuropsychologia, 1976, 14(3), 391-394.

Rhodes, L. E., Dustman, R. E., & Beck, E. C. The visual evoked response: A comparison of bright and dull children. Electroencephalography and Clinical Neurophysiology, 1969, 27, 364-372.

Richlin, M., Weisinger, M., Weinstein, S., Giannini, M., & Morganstern, M. Interhemispheric asymmetries of evoked cortical responses on retarded and normal children. Cortex, 1971, 1, 98-105.

Rummel, R. J. Applied factor analysis. Evanston, IL: Northwestern University Press, 1970.

Rydell, S. T., & Rosen, E. Measurement and some correlates of need-cognition. Psychological Reports, 1966, 19(I-V19), 139-165. (Monograph Supplement)

Shearer, S., & Tucker, D. Differential cognitive contributions of the cerebral hemispheres in the modulation of emotional arousal. Cognitive Therapy and Research, 1981, 5(1), 85-91.

Shucard, D. W., & Callaway, E. Auditory evoked potential amplitude and variability effects of task and intellectual ability. Journal of Comparative and Physiological Psychology, 1974, 87, 284-294.

Shucard, D. W., & Horn, J. L. Evoked cortical potentials and measurement of human abilities. Journal of Comparitive and Physiological Psychology, 1972, 78, 59-68.

Shucard, D. W., & Horn, J. L. Evoked potential amplitude change related to intelligence and arousal. Psychophysiology, 1973, 10, 445-452.

Snow, R. Aptitude processes. In R. Snow, P-A. Federico, & W. Montague (Eds.). Conference Proceedings: Aptitude, learning, and instruction. Volume 1: Cognitive process analyses of aptitude. (NPRDC/ONR Tech. Rep. 81-5). San Diego: Navy Personnel Research and Development Center, January 1981. (AD-A099 209)

Squires, K., Petuchowski, S., Wickens, C., & Donchin, E. The effect of stimulus sequence on event related potentials: A comparison of visual and auditory sequences. Perception and Psychophysics, 1977, 22(1), 31-40.

Tucker, D. M. Lateral brain function, emotion, and conceptualization. Psychological Bulletin, 1981, 89(1), 19-46.

Tucker, D., Shearer, S., & Murray, D. Hemispheric specialization and cognitive behavior therapy. Cognitive Therapy and Research, 1977, 1(4), 263-273.

Weinberg, H. Correlation of frequency spectra of averaged visual evoked potentials and verbal intelligence. Nature, 1969, 224, 813-815.

Wickens, C., Mountford, S., & Schreiner, W. Multiple resources, task-hemispheric integrity, and individual differences in time-sharing. Human Factors, 1981, 23(2), 211-229.

DISTRIBUTION LIST

Military Assistant for Training and Personnel Technology (ODUSD(R&AT))
Director of Manpower Analysis (ODASN(M))
Chief of Naval Operations (OP-01), (OP-11), (OP-12) (2), (OP-13), (OP-14), (OP-15), (OP-115) (2), (OP-140F2), (OP-987H)
Chief of Naval Material (NMAT 00), (NMAT 05), (NMAT 0722)
Chief of Naval Research (Code 200), (Code 440) (3), (Code 442), (Code 442PT)
Chief of Information (OI-213)
Chief of Naval Education and Training (02), (022), (N-5)
Chief of Naval Technical Training (016)
Commander in Chief U.S. Atlantic Fleet
Commander in Chief U.S. Pacific Fleet
Commander Fleet Training Group, Pearl Harbor
Commander Naval Military Personnel Command (NMPC-013C)
Commander Navy Recruiting Command
Commander Training Command, U.S. Atlantic Fleet
Commander Training Command, U.S. Pacific Fleet
Commanding Officer, Naval Aerospace Medical Institute (Library Code 12) (2)
Commanding Officer, Naval Education and Training Program Development Center (Technical Library) (2)
Commanding Officer, Naval Education and Training Support Center, Pacific
Commanding Officer, Naval Health Sciences Education and Training Command
Commanding Officer, Naval Regional Medical Center, Portsmouth, VA (ATTN: Medical Library)
Commanding Officer, Naval Technical Training Center, Corry Station (Code 101B)
Commanding Officer, Office of Naval Research Branch Office, Chicago (Coordinator for Psychological Sciences)
Director, Defense Activity for Non-Traditional Education Support
Director, Naval Civilian Personnel Command
Director, Naval Education and Training Program Development Center Detachment, Great Lakes
Director, Naval Education and Training Program Development Center Detachment, Memphis
Director, Training Analysis and Evaluation Group (TAEG)
President, Naval War College (Code E114)
Superintendent, Naval Postgraduate School
Commander, U.S. Army Soldier Support Center, Fort Benjamin Harrison (Human Dimensions Division)
Commander, Army Research Institute for the Behavioral and Social Sciences, Alexandria (PERI-ASL)
Director, U.S. Army TRADOC Systems Analysis Activity, White Sands Missile Range (Library)
Chief, Army Research Institute Field Unit--USAREUR (Library)
Chief, Army Research Institute Field Unit, Fort Harrison
Commander, Air Force Human Resources Laboratory, Brooks Air Force Base (Scientific and Technical Information Office)
Commander, Air Force Human Resources Laboratory, Lowry Air Force Base (Technical Training Branch)
Commander, Air Force Human Resources Laboratory, Williams Air Force Base (AFHRL/OT)
Commander, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base (AFHRL/LR)
Program Manager, Life Sciences Directorate, Bolling Air Force Base

Commanding Officer, U.S. Coast Guard Institute
Commanding Officer, U.S. Coast Guard Research and Development Center, Avery Point
Superintendent, U.S. Coast Guard Academy
Director, Science and Technology, Library of Congress
Defense Technical Information Center (DDA) (12)

DATE
FILMED

8